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OPECONOMICS: How Do Cooperative and Non-Cooperative Game Theory Models Explain Cartel Formation and Price Fixing Strategies In The Global Oil Market?

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Abstract

Over the years, oil has become a significant source of geopolitical conflict.The present work analyzed the behaviour of member nations of the OPEC cartel and their economic interactions with nations both within and outside the cartel. We will see how game theory models such as repeated Nash equilibria, explain activities such as collusion, cheating within a cartel, and price wars in the global oil market. I take a quantitative approach in designing most of these payoff matrices to show how revenue maximizing actions from the players brings widespread consequences to citizens across the globe who are dependent on oil for a multiplicity of uses. This real world analysis brings to the forefront the very reasons why a mostly ineffective cartel such as OPEC still exists, and what shortcomings of theirs keeps them from meeting all of their set goals while being at odds with the values of the free market.

Introduction

The conflict of interest between the producer and the consumer has been one of the most complex relationships in economics, not only because the two have different goals, but also because what both of them do to ensure that the market favours them. A cartel is one of the means by which producers in markets ensure that the balance tips in their favour as they collude to enforce policies that raise prices and lead to better payoffs for members of that cartel. That is the core of why the Organization of the Petroleum Exporting Countries (OPEC) exists, but it does not explain why, for example, members in the cartel cheat or why they make suboptimal choices in certain situations. Such enquiries are required to explain the rationale behind OPEC being considered an ineffective cartel in terms of member compliance (Misperceptions of OPEC Capability and Behavior, 2023).

Game theory models these strategic interactions mathematically, and offers explanations of why players of a game make a particular decision. There are majorly two approaches to game theoretic models: i) a cooperative one where players form coalitions or in this case, a cartel, to achieve mutually beneficial outcomes and ii) a non-cooperative one where the two players compete with each other in the truest sense and fight for each other's share of revenue. To understand the oil market well, knowledge of decision making in both of these situations is a prerequisite because the two approaches are simultaneously embedded in the modus operandi of nations in OPEC. Cartelization in general is not an encouraged practice when we talk about free trade and open competition which makes the case of OPEC even more interesting, especially since most cartels are considered illegal in different parts of the world.

A systematic approach then becomes necessary for analysis and prediction of OPEC's decision making and the first step is in understanding how they are able to influence oil prices so much. Every OPEC country has an agreed upon production capacity that they must adhere to, which are popularly called 'quotas' in most literature. When OPEC members limit production and drive up oil prices through scarcity, they should improve payoffs for each nation. In this paper, we analyze (i) how that happens and (ii) what happens when members cheat and produce over and above their assigned quantity. This is important because since its formation, OPEC has struggled to keep its members from cheating and has sometimes even fallen into price wars as we will see later in the paper. Through this, we aim to answer two things: (i) can cheating among OPEC members actually be stopped, and (ii) is the influence of the cartel of such magnitude that it puts consumer firms on the backfoot in terms of their own production?

In this paper, section 1 explores previous literature on the theme. An overview of OPEC as an organization is followed by a review of the forms of cartelization in the oil market. The incentives and choices for firms in a cartel are explored in this section, along with the on-ground functioning of OPEC. To understand price wars in later sections, a brief overview of OPEC's interactions with the rest of the oil producers is also highlighted in this section. Section 2 consists of the methodology that has been used in construction of the game and the eventual payoff matrices. The data set is then analyzed in Section 3 using the methodology presented previously and results are concluded. Section 4 discusses the findings and if they are consistent with the original conjecture. In Section 5, the findings are summed up along with limitations of the analysis and alternative suggestions for the organization under review.

Literature Review

1.1 About OPEC

The Organization of the Petroleum exporting Countries (OPEC) exists in the contemporary globalized world as one of the most famous examples of a "legal" cartel. The organization consists of the major oil producing countries in the world like Saudi Arabia, Venezuela, Iran, Iraq, Kuwait and also an extension organization called OPEC+ which has historically consisted of countries like Russia to collude on policies. Its headquarters are in Vienna, Austria.

OPEC was formed on the very basic economic problem of the allocation of a scarce resource like oil, which became increasingly important in the mid-20th century due to the scaling of industries like automobiles and aviation. The founding members hold nearly 40% of the world's oil, and their actions in the global oil market have significant repercussions in the price of oil and the overall development of nations (Natasha Turak, 2025). Therefore, the organization functions by deciding quotas for oil production of each member nation to stabilize oil prices. This means that member nations, in theory, do not produce oil beyond their decided quantities. As discussed in Robert Mabro's paper "OPEC and the Price of Oil", OPEC nations' influence on the global market is never so complete that they fully dictate prices, but is of such degree that allows most institutions to predict the direction that the prices will go in as a result of their actions (Robert Mabro, 1992).

There are a couple of reasons why there are no legal repercussions for OPEC's collusive activities. First, they have historically labelled a lot of their production cuts as 'sustainable' initiatives for non-renewable resources, leading to a lack of realistic conviction by the international community. Second, since they are an international organization, there is only so much that is possible in the form of callout mechanisms and accountability measures.

Before exploring the process of the actual cartel formation, it is important to understand the foundational objectives and goals that OPEC as an organization has, and as illustrated in most literature, it has chiefly been pushing the prices of oil to the effect of getting member nations the highest possible payoffs. The quotas themselves are placed around 90% of total production capacity of each nation (Misperceptions of OPEC Capability and Behavior, 2023), and as we'll see in the next section, the members that cheat beyond this quantity benefit over other members. OPEC also has seen the United States as a rival producer and its policy also keeps in mind reducing US influence on oil prices.

1.2 Cartelization and price fixing in OPEC

In her paper "On Collusive behavior: Models of Cartel Formation, Organizational Structure, and Destabilization", Julia Fischer gives an empirical as well as an intuitive understanding of cartel formation in a game theory context. It is described that cartel members find themselves in a classic Prisoner's dilemma game, where each member has two choices: To stick to collusive behavior or deviate from the collusive agreement, which are both situations that are observed with OPEC members. In the former, the nation must stick to the decided production quotas which is optimal for collective benefit and as we'll see later on in this paper, the payoffs offer least opportunity cost if the behavior is collusive. In the latter, the producing nation can cheat its quotas to maximise individual benefit to its trade, where it reduces the payoffs and hence revenue, for the other members of the cartel given that they stick to their quotas (Julia Fischer, 2011). To push profits, this kind of cheating is often seen in the OPEC cartel (we will later observe the case of Gabon) and sometimes leads to conflict between member nations which in a circle leads them all in a non-cooperative model again. We see in "Understanding Crude Oil Prices" by James D. Hamilton, the extent of this price fixing and its effect, but it can be inferred that it is to avoid precisely this situation that members of a cartel still stick together even after cases of cheating to avoid slumping oil prices. In this paper we also see that OPEC in itself is not the most effective cartel because it fails to punish cheating members effectively and does not have proper mechanisms to deter the 'cheating' behavior mentioned earlier (James D. Hamilton, 2008). It becomes important since this is what tells us how relevant OPEC is today.

1.3 Interaction of OPEC policies with the rest of the global market

OPEC's behavior as a price-fixing cartel not only creates game-like-situations for its member nations, but also creates an influential position as a unified player in the global oil market. A paper titled "The Russia-Saudi Arabia oil price war during the COVID-19 pandemic" written by Richie Ruchuan Ma and others illustrates to great effect what non-cooperative action can do in context to the global oil prices. It focuses on the Saudi Arabia - Russia oil price war that took place in March 2020, and led to a considerable fall in oil prices in international markets. This happened after the organization OPEC+ was devising cooperative strategies to push up global oil prices (Richie Ruchuan Ma et al. , 2021). When countries in a cartel think that it is no longer in their best interest to keep cutting production like in Russia's case, they often end up in a game theoretic situation which was the very reason the nations colluded: to avoid price wars. The aforementioned paper takes careful analysis of various payoff matrices to determine the best decision in these cases, which is why this paper will cover payoffs extensively in later sections. What is to be kept in mind while observing the price war is that it was set in motion in the pretext of the COVID-19 pandemic, when Saudi Arabia announced that it will increase oil production from 9.7 million barrels per day (bpd) to 12.3 million bpd (Jillian Ambrose, 2020). In such a non collusive action, Russia entered a prisoner's dilemma where the dominant strategy was to increase production.

The overall aim of this section in addition to summarizing existing literature on the subject was to set a context to the organization under review and understand how nations' actions influence oil prices around the globe, which in turn determines how affordable the resource is to consumers. In further sections, we will look at the methodology for this paper and if the data analysis is coincident with what game theory suggests.

Methodology

Case I

To achieve the aforementioned ends of our paper, a game for both situations had to be designed. Secondary data from various online sources is taken for analysis. The actions of nations in the oil market is modelled by using a Nash equilibrium for every production decision of the country, which is discussed later in this section. This is used in all situations under study where the below mother equation helps to conclude missing variables in subsequent functions:

Payoff to nation i: $P(Q) \times q_i - C_i(q_i)$ (1)

Here, Q represents the world quantity or the sum of all nations' production in the market. $P(Q)$ describes the demand for oil by presenting price as a function of quantity, q_i represents nation i's quantity produced and $C_i(q_i)$ stands for nation i's cost function. The above function is taken to set up an example demand function for the oil market:

$$Q(P) = kP^{-r} \quad (2)$$

Here, r is the magnitude of the price elasticity of demand, and k is a constant that we need to determine. Hence we find the average price of oil in 2023 (EIA, 2024) and the global oil production in 2023 in barrels per day (bpd) as a reasonable estimate (Statista, 2023). The price of Brent crude oil is taken to be \$83 a barrel, and global oil production is taken at 96,376,000 bpd. By plugging the values in and taking r as 0.13 (Caldara et al. , 2016):

$$QP^{r} = k = 96{,}376{,}000 \times 83^{0.13} = 1.71178 \times 10^{8} \quad (3)$$

These values are used in all payoff matrices in the Nash game to determine prices and revenue payoffs for nations.

To illustrate the price war between Russia and OPEC, the representative of OPEC is taken to be Saudi Arabia. Therefore, the players in the game are given as Russia and Saudi Arabia. Since we need to show revenue payoffs for both nations, we start by modelling cost functions for production as:

Russia: $\square_{\square}(\square_{\square}) = 21.611\square_{\square}$ (4)
Saudi Arabia: $\square_{\square}(\square_{\square}) = 12.439\square_{\square}$ (5)

Here, $\square_{\square}$ is Russia's production and $\square_{\square}$ is Saudi Arabia's production. For the sake of reference, the change by Russia in its production quota of baseline production or increased production is taken as the two choices that it has to maximise payoffs. Since it increases the production by 300,000 bpd to take the production from 10.4m barrels to 10.7m barrels, the two quantities are the high and low quantities that Russia chooses from. Similarly, Saudi Arabia responds to the production change by scaling production from 9.7m barrels to 12.3m barrels. The payoff matrix that then defines the Nash equilibrium is then defined as:

Table 1

Game	**Payoffs in $M per day**		**Russia**	
			Barrels per day	
			10400000	**10700000**
Saudi Arabia	**Barrels per day**	**9700000**	$\$(\square_1, \square_2)$	$\$(\square_1, \square_2)$
		12300000	$\$(\square_1, \square_2)$	$\$(\square_1, \square_2)$

This game is a repeating one in a price war, as the responding nation almost always tries to match the competitor's quantity. The variables x,y,z and m stand for the revenue that nations get at the quantity supplied, for which the earlier cost functions and payoff equations were used. The subscript 1 stands for Saudi Arabia's revenue and the subscript 2 represents Russia's revenue. These also stand for the results that are produced in the end which are expected to be $(\square_1, \square_2) < [(\square_1, \square_2), (\square_1, \square_2), (\square_1, \square_2)]$.

To determine revenue for both nations, preceding games with the same conditions are played which first give values of the price for each combination of decisions:

Table 2

Price				
			Russia	
			Barrels per day	
			10400000	**10700000**
Saudi Arabia	**Barrels per day**	**9700000**	57.05013858	55.36723461
		12300000	44.17772191	42.91645282

This gives the first indication of consistency with the initial idea of both nations being worse off by increasing production. These prices are calculated through taking price elasticity of demand and quantity produced of the nations as a constant.

Case II

Similarly, a Stackelberg model is used to determine Gabon's incentive to cheat its quota. As explained before, this paper also seeks to illustrate non-cooperative theory by showing that for *ceteris paribus*, revenue increases for cartel members as they produce more than their assigned quantity. In this game, Gabon already expects its other cartel members to increase production in response to price increases (since cheating has historically happened in OPEC), therefore they follow the dominant strategy in this case which is to increase production first and reap the benefits before the secondary response of other players to increase production, which brings the price back down. The following matrix models two different situations – one where the supply elasticity of oil remains zero and the rest of the world is unresponsive to Gabon's action, and the other where the supply elasticity is given to be 0.13 (Caldara et al., 2016):

Table 3

	Gabon	
	Baseline	**Obey quota**
Output	196000	177000

Stackelberg models have used residual functions to calculate responses for the rest of the world. The quota for Gabon set by OPEC in 2023 was 177,000 bpd, which it cheated by producing 196,000 bpd (Paraskova, 2023). The cost of production for Gabon was taken as that of the highest cost producer in 2021, that is, $67.18. The real value in 2023 was found to be $74.55 when adjusted for inflation. Accordingly, average oil price in 2023 was taken as $83 per barrel (French, 2024). Therefore, all needed values are obtained for calculation of the actual results. For the second scenario, we require a supply parameter in order to obtain the output from the rest of the world as a result of Gabon production cut. It is determined by the equation below:

$$\text{Output from the rest of the world} = (\text{supply parameter}) \times \text{price} \qquad (6)$$

Using this supply parameter, we determine the effect on the price of oil after Gabon cuts production, and see if the outcome differs from the first result.

Results

Case I

We sum up the total production by Russia and Saudi Arabia in the following:

Table 4

Russia and Saudi Arabia output				
			Russia	
			Barrels per day	
			10400000	**10700000**
Saudi Arabia	**Barrels per day**	**9700000**	20100000	20400000
		12300000	22700000	23000000

The payoffs for each country are obtained by the initial equation that models revenue as sales minus cost:

Table 5

Saudi payoffs, $M				
			Russia	
			Barrels per day	
			10400000	**10700000**
Saudi Arabia	**Barrels per day**	**9700000**	432.7280442	416.4038757
		12300000	390.3862795	374.8726697

Table 6

Russia payoffs, $M				
			Russia	
			Barrels per day	
			10400000	**10700000**
Saudi Arabia	**Barrels per day**	**9700000**	368.5670413	361.1917103
		12300000	234.6939079	227.9683452

Hence the final, rounded off revenue of both nations as a result of the game theoretic interaction is as follows:

Table 7

Game	Payoffs in $M per day		Russia	
			Barrels per day	
			10400000	**10700000**
Saudi Arabia	**Barrels per day**	**9700000**	(433, 369)	(416, 361)

		12300000	(390, 235)	(375, 228)

The results are consistent with the prediction formed in section 3, where $(\square_1, \square_2) < [(\square_1, \square_2), (\square_1, \square_2), (\square_1, \square_2)]$.

Case II

The Stackelberg model requires the first player (that is, Gabon) to make the first move before an expected response. The below observation assumes the rest of the world supplies oil inelastically, that is, the elasticity is 0:

Table 8

	Gabon	
	Baseline	**Obey quota**
Output	**196000**	**177000**
Oil price	83	84.80355997
Revenue	16268000	15010230.11
Cost reduction relative to baseline	N/A	-1416618.584
Change in profit		158848.6982

Here, the baseline is the quantity produced after increasing production. The oil price for the alternative scenario of complying with the quota is calculated by the earlier demand function.

The results in this scenario are inconsistent with our initial conjecture, with there being an increase in revenue after the production cut. However, in the real world, a Stackelberg model is observed where the supply elasticity of oil is not perfectly inelastic. The game below assumes that the rest of the world supplies oil with a supply elasticity of 0.13:

Table 9

	Residual demand functions	
	Gabon	
	Baseline	**Obey quota**
Output	**196000**	**177000**
Monthly output from the rest of the world	6612333.333	6629093.178
Total monthly output	6808333.333	6806093.178
Output from the rest of the world=(supply parameter)*price		
Others' output=83*supply parameter		

Supply parameter		
79666.66667		
Price	83	83.21037462
Quantity demanded		6806093.178
Error		0.000006621703506
Gabon revenue	16268000	14728236.31
Cost reduction relative to baseline		-1416618.584
Change in profit		-123145.1083

Here, the price when Gabon cuts production is determined by dividing the output from the rest of the world by the supply parameter. We observe that the margin of error is almost negligible between total monthly output and quantity demanded at the price. In this game, the result shows a substantial decrease in profits as opposed to the first scenario.

Discussion

The case I result perfectly proves how increasing production for both Russia and Saudi Arabia results in a mutually worse off outcome for both countries, yet that is what happens in reality. Consistent with the initial conjecture, the findings indicate that the combination of decisions by Russia and Saudi Arabia in the price war affect the world in two ways. One, it increases global production and leads to an increase in the quantity demanded of oil, increasing oil prices in the global market. Two, the resulting revenues for both nations are significantly lesser than if the production were to stay at the baseline. If they had colluded to cooperate and maintain the quotas, it would have led to a better payoff for both nations. Interestingly, either of these nations are still better off if they do not react to the actions of the other producers. However, to grab market share and due to added geopolitical reasons which could further decrease profits, competition becomes necessary for both nations that creates a game theory situation and helps us understand price fixing strategies.

In case II, we observe results under two different assumptions. In the first, the supply elasticity of oil is taken to be 0, and in the second it becomes more elastic at 0.13. The latter is a more practical assumption, considering that supply parameters make oil elastic in residual demand functions. The outcome of the first is rather perplexing, where it shows that Gabon loses profit by increasing production, something not seen in the real world. However, under the second assumption we see a more expected result which proves that in cartels, members who cheat beyond their agreements benefit in revenue. This explains cheating behaviour in cartels and also why it is important for the cartel to make sure that members comply with their quotas.

However, this result is not a universal one and there are limitations to both the data and the context to which they are applied. For example, the data for both cases is taken under different circumstances and due to factors like supply chain issues, production technology and geopolitical factors like reactions of other producers, data taken during different time periods will give different outcomes and possibly different inferences. Secondly, there can be a different order of reactions by more than one nation in the case of Gabon, which makes the game more complex.

Conclusion

Through this paper, we get insightful learnings about oil prices and producer behaviour. What this paper has done is extend the existing research about cartels and oil and also provide a quantitative analysis to the general notions of a cartel. I discussed payoffs for Saudi Arabia and Russia, provided an in-depth learning about cartel formation and created residual demand functions to model Gabon's decision making according to the rest of the world.

The question then arises – how can OPEC be more effective as a cartel? The main concern regarding the same is that OPEC doesn't punish members accordingly, which leads to constant cheating in OPEC within certain time periods (Misperceptions of OPEC Capability and Behavior, 2023). Ideally, the key is to set severe consequences for members in cases of non compliance so that they are forced to leave the cartel. Since this is what keeps the cartel together, it makes sense for the cartel to not keep cheating members and be less tolerant. However, OPEC has failed in the past to enforce such punishments, and the leverage has been used by dominating nations like Saudi Arabia to bypass quotas (Jim Krane, 2019). Since a majority of the OPEC countries are in the middle east and have good relations historically, such strict impositions seem unlikely in the future. The main aim of this study was to show how game theory explains 'eccentric' behaviour in the oil market, which it does so by modelling situations where unusual decisions are made by producers and illustrate the rationale through mathematical analysis.

The inferences drawn from the results are consistent with the initial conjecture of 'shared compromises' for members of a cartel, and add meaningfully to the existing research on game theory in cartels. However, the volatility of the global market prevents these results to be applicable universally and coming up with a general model for all strategic interactions in price fixing is extremely complex. The oil market is continuously evolving as a result of depleting resources, and mechanisms to obtain profits remain something to be explored further.

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Author's Biography

Shreyas Shah is a rising grade 12 student at Welham Boys' School, Dehradun in India. He is a passionate student of economics and wants to pursue the subject at an undergraduate level to further his knowledge about market dynamics and microeconomic decision making. He has previously been a part of the prestigious Finance Research Fellowship of the Shri Ram College of Commerce, University of Delhi, and has been a part of a Summer Program for Business & Economics at the National University of Singapore. His future ambitions lie in consulting and finance, where he plans to apply his knowledge of economics to make a positive impact in organizations.

References:

1. Hamilton, J. D. & Department of Economics, University of California, San Diego. (2008). Understanding crude oil prices. In Department of Economics, University of California, San Diego. https://econweb.ucsd.edu/~jhamilton/understand_oil.pdf
2. Krane, J. & The Arab Gulf States Institute in Washington (AGSIW). (2019). Does Saudi Arabia need OPEC? The Arab Gulf States Institute in Washington. https://agsiw.org/wp-content/uploads/2019/11/Jim-Krane_Saudi-OPEC_ONLINE-1.pdf
3. Ambrose, J. (2020, March 11). Saudi Arabia steps up oil price war with big production increase. The Guardian. https://www.theguardian.com/world/2020/mar/11/saudi-arabia-oil-price-war-production-increase-aramco
4. Turak, N. (2025, April 4). Why OPEC+ is accelerating oil production as prices are tanking and tariffs hammer markets. CNBC. https://www.cnbc.com/2025/04/04/why-opec-is-accelerating-oil-production-as-prices-tank-tariffs-hit.html
5. Paraskova, T. (2023, April 3). Small OPEC producer to start new oil project despite pledge to cut output. OilPrice.com. https://oilprice.com/Latest-Energy-News/World-News/Small-OPEC-Producer-To-Start-New-Oil-Project-Despite-Pledge-To-Cut-Output.html
6. Fischer, J. (2011). On collusive behavior models of cartel formation, organizational structure, and destabilization (By Universität Hohenheim; D. Hachmeister, U. Schwalbe, & J. Haucap, Eds.). https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=e9a1213ca5d54aa41503fd9efa2c318b90b9bf5e
7. Misperceptions of OPEC capability and behavior. (2023, November 2). Cato Institute. https://www.cato.org/policy-analysis/misperceptions-opec-capability-behavior
8. Crude oil prices increased in 2021 as global crude oil demand outpaced supply - U.S. Energy Information Administration (EIA). (n.d.). https://www.eia.gov/todayinenergy/detail.php?id=50738
9. Ma, R. R., Xiong, T., & Yukun Bao. (2021). The Russia-Saudi Arabia oil price war during the COVID-19 pandemic. In Energy Economics (Vol. 102, p. 105517). https://pmc.ncbi.nlm.nih.gov/articles/PMC8652835/pdf/main.pdf
10. Mabro, R. (1992). OPEC and the price of oil. The Energy Journal, 13(2), 1–17. https://doi.org/10.5547/issn0195-6574-ej-vol13-no2-1
11. Brent crude oil prices averaged $19 per barrel less in 2023 than 2022 - U.S. Energy Information Administration (EIA). (n.d.). https://www.eia.gov/todayinenergy/detail.php?id=61142
12. Statista. (2024, September 25). Global oil production 1998-2023. https://www.statista.com/statistics/265203/global-oil-production-in-barrels-per-day/
13. Caldara, D., Cavallo, M., & Iacoviello, M. (2016). Oil price elasticities and oil price fluctuations. In Board of Governors of the Federal Reserve System, International Finance Discussion Papers (No. 1173). https://www.federalreserve.gov/econresdata/ifdp/2016/files/ifdp1173.pdf